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N. K. Fageria^{ab}; V. C. Baligar^a

^a USDA-ARS, ASWCRL, Beckley, WV, USA ^b CNPAF-EMBRAPA, Goiania-GO, Brazil

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RESPONSE OF LEGUMES AND CEREALS TO PHOSPHORUS IN SOLUTION CULTURE

N. K. Fageria^{1,2} and V. C. Baligar¹

¹USDA-ARS ASWCRL, Beckley, WV 25802-0867 USA

²CNPAF-EMBRAPA, Goiania-GO, Brazil

ABSTRACT

Phosphorus deficiency is one of the important growth limiting factors in crop production in many regions of the world. The objective of this study was to evaluate responses of alfalfa (Medicago sativa L.), red clover (Trifolium pratense L.), common bean (Phaseolus vulgaris L.), wheat (Triticum aestivum L.) and rice (Oryza sativa L.) to concentrations of P in nutrient solution. The P treatments applied were 5, 50, 100, 200 and 400 μ M P. All crop species significantly responded to an increase in external P concentrations. The optimum P concentration for maximum growth varied with crop species, but it was higher for legumes than for cereals. Rice needs minimum as red clover maximum P concentration for maximum growth in nutrient solution as compared to other crops species. Concentrations of K, Zn and Mn were significantly affected in all crop species with P

addition. Suggesting positive effects of P in ameliorating Mn toxicity if this element is present in growth medium. Increasing concentrations of P in growth medium produce negative effect on K and Zn nutrition. Growth parameters and plant nutrients concentration and uptake correlation studies showed that legumes are more responsive to P fertilization as compared to cereals.

INTRODUCTION

In acid soils of the tropical, as well as temperate regions, P deficiency is one of the important yield limiting factors around the world (Goedert et al., 1982; Mahler and Menser, 1988). Phosphorus fertilization and liming are important practices to improve crop yields on these soils (Kamprath and Foy, 1985).

Low natural P status and high P-fixation capacity are the main reasons of P-deficiency in these soils. The concentration of phosphate in soil solution may vary from 10 mmol m^{-3} P in well fertilized soils to 0.1 mmol m^{-3} P or lower in deficient soils (Asher and Loneragan, 1967; Bielecki, 1973). The high P-fixation capacity of acid soils is related to high allophane content and a large amount of exchangeable Al (Coleman et al., 1960; Bromfield, 1965; Fields and Parrott, 1966; Jones et al., 1979; Jones and Benson, 1975; Mahler, 1984). Aluminum saturation of more than 80% has been reported in humid tropical and savanna areas of Latin America (Goedert et al., 1982) and greater than 70% in the Appalachian region of the United States (Wright et al., 1987). Growth of almost all cereals and legume crops is reduced when Al saturation is higher than 50% (Fageria et al., 1988). On such soils, large and frequent P fertilizer applications are required for successful cereals and legume production. Fertilizer placement and timing of P application may also be of major importance (Fox and Kang, 1978).

The objective of this study was to evaluate the response of alfalfa, red clover, common bean, rice and wheat to different P concentrations in nutrient solution. Plant growth parameters and tissue nutrient status were used as indices of evaluating crop species response to external P concentrations.

MATERIALS AND METHODS

An experiment was conducted under a controlled environment to study the response of alfalfa (Medicago sativa L. cv. Arc), red clover (Trifolium pratense L. cv. Kenstar), common bean (Phaseolus vulgaris L. cv. Carioca), rice (Oryza sativa L. cv. Rio Paranaíba) and wheat (Triticum aestivum L. cv. Yecorra Rojo) to different concentrations of P in nutrient solution. The composition of the nutrient solution was (Baligar and Barber, 1978) N 3 mM as $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, K 1 mM as K_2SO_4 , Ca 1.5 mM as $\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$, Mg 1 mM as $\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$, B 46 μM as H_3BO_3 , Mn 9 μM as $\text{MnCl}_2 \cdot 4\text{H}_2\text{O}$, Zn 0.7 μM as $\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$, Cu 0.3 μM as $\text{CuSO}_4 \cdot \text{H}_2\text{O}$, Fe 75 μM as FeDTPA and Mo 0.07 μM as $(\text{NH}_4)_6\text{Mo}_7\text{O}_{24} \cdot 4\text{H}_2\text{O}$. Phosphorus concentrations were 5, 50, 100, 200 and 400 μM supplied through KH_2PO_4 . The increase in K concentrations with addition of KH_2PO_4 were compensated by addition of KCl so as to maintain K levels. The pH of the solution was adjusted to 5.5 initially and left unadjusted thereafter. During the experimentation, nutrient solution was continuously aerated. The pH of the nutrient solutions were monitored at the time of harvesting of each crop species. It ranges from 6.9 to 7.3 for alfalfa, 5.4 to 7.5 for red clover, 6.9 to 5.0 for bean, 6.7 to 7.7 for rice and 7.0 to 7.4 for wheat from lower to higher P concentrations.

A split-plot experimental design was used with 1.7 liter nutrient solution in plastic containers. Crop species served as main treatments and P-concentrations as sub-treatments, and each treatment was replicated three times. Nutrient solution was not

changed during experimentation and solution level in each container was maintained through deionized water.

The climatic conditions in the growth chamber during the experimentation were 14 h of $530 \mu\text{moles s}^{-1} \text{m}^{-2}$ light intensity, day temperature was 28°C and the relative humidity was 60%. At night, the temperature and relative humidity were 22°C and 80%, respectively.

Seeds of five crop species were germinated in paper towel and 6 to 8 day old seedlings were transplanted to each container containing different concentrations of P. Alfalfa, red clover, rice and wheat were 8 plants per container and in the case of bean, there were 4 plants per container. Rice, wheat and bean plants were harvested 14 days after transplanting in nutrient solution.

Alfalfa and clover were harvested after 22 days growth in nutrient solution. Total root length of each crop species was measured with a Comair root length scanner. Roots and tops were dried to constant weight in a forced-draft oven at about 65°C and then milled. Plant material was wet digested in a $\text{HNO}_3/\text{HClO}_4$ (4:1) mixture. Elemental determinations were made by inductively coupled plasma emission spectroscopy (ICP).

Yield and tissue nutrient status data were statistically analyzed by analysis variance. Statistical Analysis System (SAS) Program was used to calculate regression equations and correlation coefficients relating plant growth, tissue nutrient concentrations, and uptake.

RESULTS AND DISCUSSION

All growth parameters of five crop species were significantly affected by the P treatments (Table 1). Similarly, a significant crop species X P interactions was observed for all growth parameters studied except root length. Maximum roots and shoots weight of alfalfa and common bean was achieved at $200 \mu\text{M}$ P concentra-

TABLE 1
F-values for growth parameters across 5 crop species

Source of Variance	Shoot Dry Wt.	Root Dry Wt.	Root Length	SGI	RGI
Species (SP)	262.87**	49.23**	43.75**	6.51**	2.68*
P Conc. (P)	125.21**	5.49**	3.36*	121.02**	9.30**
SP X P	9.77**	1.80NS	2.49**	3.19**	3.35**

*, **, NS = Significant at 5 and 1% probability levels and non-significant, respectively.

Shoot growth index (SGI) or Root Growth Index (RGI) =
[Dry wt. at any P level/Maximum dry wt.] X 100.

tion (Table 2). In case of red clover the maximum weight of root and shoot was obtained at 400 μ M P concentration. Wheat produced maximum dry weight of roots at 400 μ M but shoot weight was maximum at 200 μ M P. Rice produced maximum dry weight of roots at 50 μ M P and shoot weight at 100 μ M P concentration. Critical P levels for the production of maximum dry weight of shoot calculated on the basis of quadratic equations for each crop species are presented in (Table 3). The critical P concentration was the highest (315 μ M) for red clover and the lowest (256 μ M) for rice. Coefficient of determination (R^2) values were highest for red clover and minimum for rice.

Data related to F-values of nutrient concentration, uptake and efficiency ratio and influence of P on nutrient concentrations and uptake are presented in Tables 4, 5 and 6. There was a highly significant effect of crop species, P treatment and species X P interaction for all nutrients concentration, uptake and efficiency ratios (Table 4). Tissue P concentration (P content per unit dry matter) and uptake (P conc. X dry matter)

TABLE 2
Influence of P concentrations on growth parameters of 5 crop species.

P conc. μM	Shoot Dry Wt. g/pot	Root Dry Wt. g/pot	Root Length m/pot	Shoot Growth Index ^a	Root Growth Index ^a
<u>Alfalfa</u>					
5	0.26	0.18	17.9	8	26
50	2.50	0.65	58.3	77	90
100	2.95	0.52	45.1	91	72
200	3.23	0.72	61.0	100	100
400	3.15	0.65	53.3	97	90
LSD (0.05)	0.46	0.19	17.8	14	25
<u>Red Clover</u>					
5	0.15	0.11	17.9	11	40
50	0.68	0.14	20.6	50	48
100	0.88	0.18	23.2	65	64
200	1.30	0.28	26.4	96	97
400	1.36	0.29	21.4	100	100
LSD (0.05)	0.28	0.07	7.5	21	24
<u>Common Bean</u>					
5	1.42	0.73	77.8	34	59
50	3.18	0.98	101.6	76	80
100	4.17	1.22	144.6	100	99
200	4.18	1.23	166.5	100	100
400	3.97	1.10	154.1	95	89
LSD (0.05)	0.51	0.59	77.4	12	48
<u>Wheat</u>					
5	0.85	0.61	58.9	33	51
50	1.06	1.09	111.5	81	92
100	2.39	0.90	72.8	94	76
200	2.54	0.74	48.2	100	62
400	2.13	1.19	85.6	84	100
LSD (0.05)	0.72	0.46	43.9	29	39
<u>Rice</u>					
5	0.43	0.48	68.4	42	97
50	0.84	0.49	67.2	82	100
100	1.03	0.45	72.9	100	91
200	0.91	0.43	69.6	88	87
400	0.93	0.33	50.6	90	67
LSD (0.05)	0.13	0.09	25.3	12	20

^aShoot or root growth index = [Dry wt at any P levels/Maximum dry wt.] X 100

TABLE 3

Regression equations relating shoot growth index (Y) and P concentrations (X) of five crop species, and critical P levels.

Crop	Equation	Critical P Level (μM)	R ²
Alfalfa	$Y = 22.26 + 0.74P - 0.0014P^2$	264	0.79*
Red Clover	$Y = 13.01 + 0.63P - 0.0010P^2$	315	0.91**
Common Bean	$Y = 41.54 + 0.58P - 0.0011P^2$	264	0.81*
Wheat	$Y = 42.03 + 0.58P - 0.0011P^2$	264	0.65NS
Rice	$Y = 53.01 + 0.41P - 0.0008P^2$	256	0.60NS

*, **, NS = Significant at 5 and 1% probability levels and nonsignificant, respectively.

increased with increasing P concentrations in the growth medium with all crop species. Rice and wheat were having highest P content per unit of dry matter as compared to alfalfa, clover and common bean at highest P levels. But uptake of P was highest in the common bean followed by wheat at the highest P concentration.

Concentrations of K, Ca, Mg, S, Fe, Mn, Zn and Cu significantly decreased with an increase in external concentration in alfalfa and clover (Table 5). Boron concentration was not significantly influenced in alfalfa, but in the case of clover concentration of this element decreased significantly at highest P level as compared to lowest P level. Compositions of K, Ca, Mg, Zn and Cu were decreased significantly with application of 400 μM P in nutrient solution as compared to 5 μM P concentration in case of bean. But, Fe and Mn increased with higher level of P addition in the growth medium. There was no change in B concentration with the addition of P levels.

TABLE 4

F-values for nutrient concentrations, uptake and efficiency ratios in the shoot of five crop species. Values are across the five crop species.

Variable	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
<u>Nutrient Conc.</u>										
Species (S)	69.51**	27.78**	398.00**	248.49**	63.66**	109.59**	429.24**	14.68**	9.89**	20.24**
P conc. (P)	143.20**	5.71**	19.57**	2.75*	2.27NS	1.25NS	30.98**	54.04**	12.49**	3.58*
S X P	9.39**	2.93**	17.78**	22.48**	5.33**	10.65**	10.84**	2.97**	3.12**	7.38**
<u>Nutrient Uptake (Conc. X Dry Matter)</u>										
Species (S)	14.20**	39.09**	457.27**	143.39**	145.29**	454.77**	95.88**	66.65**	22.76**	66.84**
P conc. (P)	85.16**	29.68**	69.69**	84.33*	48.33**	55.99**	13.43**	1.83NS	5.82**	42.35**
S X P	2.62**	4.33**	6.90**	4.02**	3.62**	33.15**	1.48NS	2.12*	1.10NS	2.93**
<u>Efficiency Ratio (ER = mg Dry Matter/mg Element Absorbed)</u>										
Species (S)	128.57**	39.19**	294.04**	126.61**	162.19**	62.01**	162.47**	52.92**	14.48**	21.14**
P conc. (P)	513.35**	7.33**	2.64*	2.64*	2.46NS	6.76**	27.52**	37.76**	11.14**	5.05**
S X P	28.68**	3.13**	9.41**	8.40**	6.10**	3.76**	6.73**	4.48**	2.24*	5.49**

*, **, NS = Significant at 5 and 1% probability levels and nonsignificant, respectively.

TABLE 5
Influence of P on nutrient concentrations in shoot of five crop species.

P conc. μM	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
				g kg ⁻¹				mg kg ⁻¹		
5	0.7	27.5	17.1	4.5	2.3	77.9	177.8	66.7	24.5	19.9
50	0.9	19.9	11.3	2.6	1.9	63.9	77.6	16.6	9.1	23.1
100	1.3	19.4	9.2	2.2	1.9	50.8	64.8	18.4	10.5	14.9
200	2.2	17.2	10.5	3.0	2.1	48.4	78.2	14.4	9.7	21.4
400	2.9	17.8	10.7	2.7	2.2	42.4	81.1	15.7	9.5	19.3
LSD (0.05)	0.4	3.6	1.7	0.8	0.3	11.8	13.4	14.8	5.4	6.5
<u>Red Clover</u>										
5	0.9	27.5	14.7	8.0	2.7	219.3	161.0	64.2	30.1	40.1
50	2.9	27.8	16.8	6.2	4.6	148.5	89.1	42.5	21.3	24.5
100	3.9	27.2	16.6	6.2	3.8	163.5	109.2	49.2	22.1	27.6
200	4.4	36.9	14.9	5.5	4.2	121.1	87.9	39.5	12.4	24.1
400	4.9	35.3	12.7	4.9	3.1	84.4	65.0	34.8	13.4	29.8
LSD (0.05)	1.1	1.3	2.0	1.2	0.7	43.3	34.4	12.5	12.4	4.7
<u>Common Bean</u>										
5	1.2	17.1	24.2	5.6	5.3	147.5	191.4	82.4	34.6	27.3
50	1.1	13.3	15.5	3.3	3.9	170.9	101.8	31.1	12.8	22.4
100	1.2	9.6	15.5	3.8	3.9	235.7	92.4	21.3	10.5	19.6
200	2.2	9.7	16.6	4.5	4.7	322.9	106.4	24.6	12.5	22.4
400	3.7	10.9	16.3	4.5	4.3	304.0	111.4	25.6	9.8	22.6
LSD (0.05)	0.1	3.2	1.9	0.6	1.5	62.7	11.1	6.1	9.7	4.1
<u>Wheat</u>										
5	1.1	36.5	5.4	2.2	2.8	137.9	205.4	110.9	24.7	8.6
50	1.2	27.2	4.7	2.2	3.1	64.3	197.1	41.1	13.8	6.5
100	2.5	30.3	7.4	3.1	4.6	79.4	204.1	47.3	17.6	16.9
200	4.8	23.2	6.1	2.4	3.2	47.9	176.7	33.9	13.7	18.9
400	6.7	28.1	6.8	2.8	3.5	79.7	189.1	35.9	15.0	29.8
LSD (0.05)	1.9	8.9	1.8	0.8	1.1	65.8	70.5	35.3	10.3	13.6
<u>Rice</u>										
5	0.9	33.5	6.1	3.7	3.7	85.3	1116	53.7	20.5	12.2
50	2.9	11.7	7.2	7.4	4.6	120.3	605	27.7	29.9	27.8
100	4.3	33.3	7.6	7.7	4.9	74.9	534	32.9	19.3	24.7
200	6.5	14.9	7.9	8.5	5.3	93.6	593	29.2	31.4	31.0
400	8.3	21.2	7.5	9.4	6.1	85.6	714	37.8	22.6	26.4
LSD (0.05)	0.5	14.9	0.9	0.9	0.7	35.4	184	13.4	11.4	5.3

TABLE 6
Influence of P on nutrient uptake in shoot of five crop species.

P conc. μM	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
	-----mg/pot-----					----- $\mu\text{g/pot}$ -----				
	<u>Alfalfa</u>									
5	0.2	7.1	4.4	1.2	0.6	20	46	18	7	5
50	2.2	49.9	28.4	6.4	4.6	159	194	42	23	58
100	3.7	56.1	26.8	6.2	5.5	148	191	55	31	43
200	7.2	55.7	34.0	9.8	6.6	157	253	47	31	69
400	9.3	55.8	33.7	8.3	6.8	133	254	50	30	60
LSD (0.05)	0.9	3.3	4.3	2.0	0.5	32	47	20	13	11
	<u>Red Clover</u>									
5	0.1	4.2	2.2	1.2	0.4	34	25	10	5	6
50	1.9	18.3	14.4	4.1	3.1	98	57	28	14	17
100	3.3	25.1	14.5	5.4	3.3	142	95	43	19	24
200	5.7	47.6	19.3	7.2	5.3	154	114	51	16	31
400	6.7	48.0	17.2	6.6	4.2	114	89	48	18	40
LSD (0.05)	1.4	1.5	3.9	1.3	0.9	33	22	11	10	10
	<u>Common Bean</u>									
5	1.7	24.7	34.5	8.0	7.4	212	273	117	48	39
50	3.3	41.9	49.4	10.4	12.3	535	323	99	41	71
100	5.1	40.1	64.6	15.7	16.3	985	385	88	44	81
200	9.1	40.4	69.0	18.7	19.4	1341	443	102	53	94
400	14.7	43.1	64.6	17.9	16.9	1207	442	101	39	90
LSD (0.05)	0.7	8.6	10.8	2.4	3.6	205	62	33	18	17
	<u>Wheat</u>									
5	0.9	30.7	4.6	1.8	2.4	120	175	96	21	7
50	2.5	55.8	9.7	4.6	6.6	131	406	84	28	13
100	6.1	74.5	18.3	7.6	11.2	199	509	114	44	43
200	12.4	57.9	15.5	6.1	8.0	121	450	85	35	46
400	14.3	58.0	14.3	5.8	7.3	154	404	73	31	62
LSD (0.05)	6.6	26.2	3.1	3.6	4.6	123	265	50	27	35
	<u>Rice</u>									
5	0.4	14.6	2.6	1.6	1.6	37	485	23	9	5
50	2.4	9.9	6.1	6.3	3.9	102	514	24	25	24
100	4.4	35.3	7.8	7.9	5.0	78	547	34	20	25
200	5.9	13.2	7.2	7.7	4.8	86	539	27	29	29
400	7.7	19.7	7.0	8.7	5.6	80	662	35	21	24
LSD (0.05)	0.6	16.7	1.1	1.1	0.7	35	110	10	13	8

In the case of wheat concentrations of K, Fe, Mn, Zn and Cu decreased with the addition of P, but concentrations of Mg, S and B increased. Similarly, in rice concentrations of K, Mn and Zn decreased but Ca, Mg, S, Cu and B increased. Important conclusions from the concentration data is that P application reduce the concentrations of Mn in legumes as well as cereals. This may help in ameliorating toxicity of this element in acid soils. But on the other hand, it may induce deficiency of K and Zn if these elements are not present in sufficient amount in the growth medium.

Uptake data of almost all elements (Table 6) showed an increase with an increase in external P concentrations. This is related to increase in dry matter production with increasing P levels. This means when determining increase or decrease of element with P application, concentration data (content per unit dry matter) are more useful index rather than uptake data.

Data related to nutrient utilization efficiency by 3 legumes and two cereals are presented in Table 7. Phosphorus utilization was highest at the lowest external P concentration and lowest at the highest P concentration in all the crop species. This is related to dry matter production. Among legumes, alfalfa produced maximum dry matter per unit of P absorbed followed by red clover and bean. Alfalfa was also more efficient at the highest P level as compared to two other legume species. In the case of cereals, rice was more effective in P utilization at lower P level, but wheat produced more dry weight at higher P levels per unit of P absorbed as compared to rice. This means P utilization efficiency varied with crop species and the level of external P in growth medium. Efficiency ratios were higher at the highest P level as compared to lowest P concentration in all legumes except with a few exceptions such as K and S in red clover and Fe in common bean. In cereals this trend was not observed and efficiency ratios of Ca, Mg, S, and B

TABLE 7
Influence of P on efficiency ratios for nutrients in shoots of five crop species.

P conc. μM	Efficiency ratio (ER = mg dry matter/mg element absorbed) [†]									
	P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B
<u>Alfalfa</u>										
5	1478	36	58	220	343	13	6	16	42	51
50	1141	50	88	390	539	16	13	60	117	44
100	787	52	110	474	532	20	16	55	97	71
200	448	58	96	338	488	21	13	72	109	47
400	341	57	94	378	464	24	13	65	106	53
LSD (0.05)	183	9	18	121	90	4	2	19	41	23
<u>Red Clover</u>										
5	1163	36	68	124	372	5	6	16	33	25
50	355	36	60	162	220	7	12	25	54	41
100	259	45	60	163	265	6	9	21	53	36
200	228	27	67	182	243	9	11	25	89	42
400	207	28	79	208	324	12	16	29	76	34
LSD (0.05)	91	21	9	37	46	3	4	7	42	7
<u>Common Bean</u>										
5	821	60	41	179	196	7	5	12	31	37
50	949	76	65	308	257	6	10	32	78	45
100	823	104	65	265	256	4	11	47	97	52
200	458	103	61	223	218	3	9	41	83	45
400	270	92	61	221	238	3	9	40	105	44
LSD (0.05)	68	15	7	33	65	2	1	9	28	9
<u>Wheat</u>										
5	907	28	184	460	350	8	5	10	43	129
50	832	37	212	448	313	16	5	25	78	167
100	419	34	142	348	229	14	5	21	64	78
200	220	44	165	418	317	21	5	31	81	65
400	157	36	148	363	289	16	6	30	67	35
LSD (0.05)	120	10	33	91	59	9	2	12	41	74
<u>Rice</u>										
5	1173	30	166	267	275	12	1	19	49	83
50	345	85	140	136	215	9	2	36	33	36
100	233	400	132	129	205	13	2	30	55	41
200	154	81	126	117	188	11	2	36	35	33
400	120	47	133	106	167	12	1	27	45	38
LSD (0.05)	33	45	20	15	31	3	0.3	10	18	10

[†]ER for Fe, Mn, Zn, Cu and B need to be multiplied by 10³.

RESPONSE OF LEGUMES AND CEREALS TO PHOSPHORUS

1017

TABLE 8
Simple correlation coefficients (r) between growth parameters and nutrient concentration and uptake in shoot of 5 crop species.

Variable	Alfalfa			Red Clover			Common Bean			Wheat			Rice		
	Shoot Dry Wt.	Root Dry Wt.	Length	Shoot Dry Wt.	Root Dry Wt.	Length	Shoot Dry Wt.	Root Dry Wt.	Length	Shoot Dry Wt.	Root Dry Wt.	Length	Shoot Dry Wt.	Root Dry Wt.	Length
Growth Parameters															
Shoot Dry Wt.	1.00			1.00			1.00			1.00			1.00		
Root Dry Wt.	0.88**	1.00		0.92**	1.00		0.67**	1.00		0.45NS	1.00		-0.27NS	1.00	
Root Length	0.83**	0.93**	1.00	0.59*	0.61*	1.00	0.74**	0.95**	1.00	0.21NS	0.89**	1.00	0.01NS	0.74**	1.00
Nutrient Conc.															
P	0.66**	0.51NS	0.47NS	0.85**	0.72**	0.18NS	0.42NS	0.18NS	0.42NS	0.49NS	0.20NS	-0.17NS	0.66**	-0.73**	-0.38NS
K	-0.96**	-0.91**	-0.85**	0.46NS	0.42NS	0.10NS	-0.87**	-0.54*	-0.51*	-0.64**	-0.03NS	0.15NS	-0.20NS	0.18NS	0.20NS
Ca	-0.94**	-0.76**	-0.67**	-0.37NS	-0.38*	-0.35NS	-0.83**	-0.35NS	-0.36NS	0.41NS	0.37NS	0.11NS	0.74**	-0.07NS	0.20NS
Mg	-0.84**	-0.65**	-0.58*	-0.50**	-0.82**	-0.48NS	-0.56*	-0.17NS	-0.07NS	0.47NS	0.52*	0.35NS	0.82**	-0.56*	-0.28NS
S	-0.54*	-0.56*	-0.50NS	0.19NS	-0.01NS	0.23NS	-0.50NS	-0.44NS	-0.30NS	0.43NS	0.45NS	0.35NS	0.64**	-0.79**	-0.50NS
Fe	-0.87**	-0.70**	-0.63**	-0.91**	-0.84**	-0.43NS	0.71**	0.43NS	0.61*	-0.62*	-0.04NS	0.10NS	0.01NS	0.33NS	0.14NS
Mn	-0.94**	-0.82**	-0.76**	-0.83**	-0.70**	-0.41NS	-0.90**	-0.47NS	-0.47NS	0.04NS	0.35NS	0.50NS	-0.88**	-0.07NS	-0.32NS
Zn	-0.90**	-0.81**	-0.80**	-0.82**	-0.69**	-0.42NS	-0.84**	-0.52*	-0.57*	-0.75**	-0.35NS	-0.11NS	-0.66**	-0.22NS	-0.32NS
Cu	-0.86**	-0.80**	-0.79**	-0.76**	-0.69**	-0.41NS	-0.87**	-0.62*	-0.63*	-0.46NS	0.01NS	0.16NS	0.18NS	-0.14NS	-0.16NS
B	-0.18NS	0.04NS	0.10NS	-0.61*	-0.46NS	-0.50NS	-0.75**	-0.52*	-0.49NS	0.30NS	0.36NS	-0.01NS	0.81**	-0.31NS	-0.09NS
Nutrient uptake															
P	0.77**	0.64*	0.58*	0.96**	0.91**	0.49NS	0.64*	0.34NS	0.37*	0.68**	0.22NS	-0.15NS	0.74**	-0.71**	-0.34NS
K	0.97**	0.83**	0.80**	0.94**	0.86**	0.50NS	0.82**	0.56*	0.58*	0.79**	0.62*	0.47NS	0.44NS	0.03NS	0.33NS
Ca	0.95**	0.91**	0.91**	0.96**	0.82**	0.57**	0.95**	0.77**	0.86**	0.87**	0.69NS	0.22NS	0.98**	-0.23NS	0.07NS
Mg	0.88**	0.89**	0.88**	0.96**	0.82**	0.62**	0.88**	0.66**	0.81**	0.87**	0.55*	0.32NS	0.96**	-0.48NS	-0.17NS
S	0.97**	0.83**	0.80**	0.94**	0.83**	0.67**	0.94**	0.59*	0.74**	0.84**	0.53*	0.34NS	0.32**	-0.56*	-0.22NS
Fe	0.90**	0.86**	0.84**	0.77**	0.58*	0.62*	0.88**	0.54*	0.70**	0.79NS	0.55*	0.49NS	0.69**	0.04NS	0.09NS
Mn	0.96**	0.86**	0.88**	0.88**	0.75**	0.64**	0.86**	0.70**	0.86**	0.87**	0.59*	0.45NS	0.68**	-0.89**	-0.69**
Zn	0.86**	0.63*	0.57**	0.95**	0.83**	0.63*	-0.32NS	0.05NS	0.01NS	0.08NS	0.19NS	0.29NS	0.60*	-0.66**	-0.33NS
Cu	0.88**	0.69**	0.63*	0.67**	0.53*	0.44NS	-0.01NS	-0.04NS	0.01NS	0.59*	0.59*	0.47NS	0.63*	-0.24NS	-0.10NS
B	0.87**	0.89**	0.86**	0.96**	0.86**	0.46NS	0.92**	0.60*	0.70**	0.61*	0.46NS	0.07NS	0.92**	-0.31NS	-0.02NS

*, **, NS = Significant at 5 and 1% probability levels and nonsignificant, respectively.

was higher at lower concentration and lower at higher concentration.

In alfalfa, red clover and common bean all three growth parameters were significantly related to each other (Table 8). In the case of wheat and rice, shoot dry weight was not related to either root weight or to root length, but root weight and root length were significantly related to each other.

The association between growth parameters and nutrient concentrations were significantly negatively correlated except P in legumes was positively correlated. Most of the correlation between growth parameters of legumes, wheat and nutrient uptake was significantly positively related, but in case of rice root dry weight and root length were negatively correlated. The correlation data for nutrient concentrations and uptakes were higher for legumes as compared to cereals. This means legumes were more responsive to P fertilization as compared to cereals and need more P supply for better yield.

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